

Optimisation of Catapult Performance Using the Taguchi Method: Identification and
Validation of Key Control Factors

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1. Objectives

The objective of this experiment was to investigate the key control factors affecting the performance of a wooden catapult, using the Taguchi method of experimental design.

The focus was to systematically vary specific adjustable settings on the catapult Band Front Position, Band Anchor Position, Stop Position and Pull-back Amount (operator dependant), to identify which factors most influenced the accuracy and consistency of projectile launches.

By applying a structured experimental matrix, the experiment aimed to predict the optimal configuration for achieving minimal deviation from a set target.

This study demonstrates how the Taguchi method can efficiently optimize mechanical systems with multiple variable inputs, using a reduced number of experimental trials.

2. Apparatus and Methodology

2.1. Apparatus

The apparatus used for the experiment was a wooden catapult (Figure 1) with the following adjustable features:

- Band Front Position: Adjustable mounting point for the front of the elastic band.

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- Band Anchor Position: Adjustable mounting point for the rear of the elastic band.
- Stop Position: Adjustable physical stop limiting the forward travel of the throwing arm.
- Pull-back: Manual operator-controlled arm draw distance (no mechanical stopper).



Figure 1 – Taguchi Catapult [1]

Other equipment included:

- Lightweight ball as projectiles.
- Measuring tape for distance measurements.
- A designated firing range and safety zone area.

Personal protective equipment such as safety goggles was not required for this experiment. However, all launches were conducted in a marked safety-controlled environment.

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Key noise factors:

- Deviation of catapult after firing (left to right) mitigated by resetting after each firing
- Operators draw distance (mitigated by adding into controls, by changing operator in different firings)

2.2. Method

2.2.1. Identification of Control Factors and Levels:

Four key adjustable factors were selected for the experiment:

- Band Front Position (levels 1 and 3)
- Band Anchor Position (levels 2 and 4)
- Stop Position (positions 1 and 3)
- Pull-back Amount (140 units or 170 units, based on operator judgment)

2.2.2. Experimental Design:

The Taguchi method was applied to efficiently assess the effects of these control factors without performing an exhaustive number of trials.

A modified L8 matrix incorporating interactions between key factors (AB and BC interactions) was used to structure the trials.

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Each experimental combination was repeated three times to obtain an average projectile range.

2.2.3. Execution:

- For each setting combination, the catapult was adjusted as per the experimental matrix.
- The same type of projectile was loaded consistently.
- The firing procedure was repeated three times per setting, with distances measured from the launch point to the impact location.
- Operators A and B conducted different runs as part of the experimental design to account for human variation.

2.2.4. Data Collection and Analysis:

- The distance travelled by each shot was recorded.
- The average range for each trial was calculated and recorded.
- The results were then analysed to determine the impact of each control factor and their interactions to identify key control factors.

2.2.5. Validation of Results:

Following the completion of the Taguchi trials, an additional validation test was performed focusing only on the two primary

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effectors identified from the Taguchi analysis: Band Front Position and Pull-back Amount.

During validation, all other settings were fixed while Band Front Position and Pull-back were varied at two levels each (Levels 1 and 3 for Band Front Position, and 140 and 170 units for Pull-back).

This secondary experiment aimed to verify the consistency of the key findings but is not included in the main Taguchi analysis.

3. Experimental data

The following data was collected from the Taguchi trials. Each configuration was tested three times, the average projectile range was then calculated.

Band front position	Band Anchor position	AB Interaction	Stop Position	Pull back	BC Interaction	Operator	Variable. Range (cm)	Shot 1	Shot 2	Shot 3
1	2	1	1	140	1	A	139	140	139	138
1	2	1	3	170	2	B	352.66667	330	345	383
1	4	2	1	140	2	B	125	120	125	130
1	4	2	3	170	1	A	318.33333	300	315	340
3	2	2	1	170	1	B	147.33333	150	147	145
3	2	2	3	140	2	A	94.333333	100	95	88
3	4	1	1	170	2	A	126.66667	125	126	129
3	4	1	3	140	1	B	87.666667	90	85	88

Table 1 – Taguchi trial results

These results produced variation tables for each control (figure 2), this showed that the key control areas were the front position and the pull back of the catapult. It is key to remember that the pull back had no physical stop, thus, the

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pull back is operator dependant, thus, producing variable results across more firings.

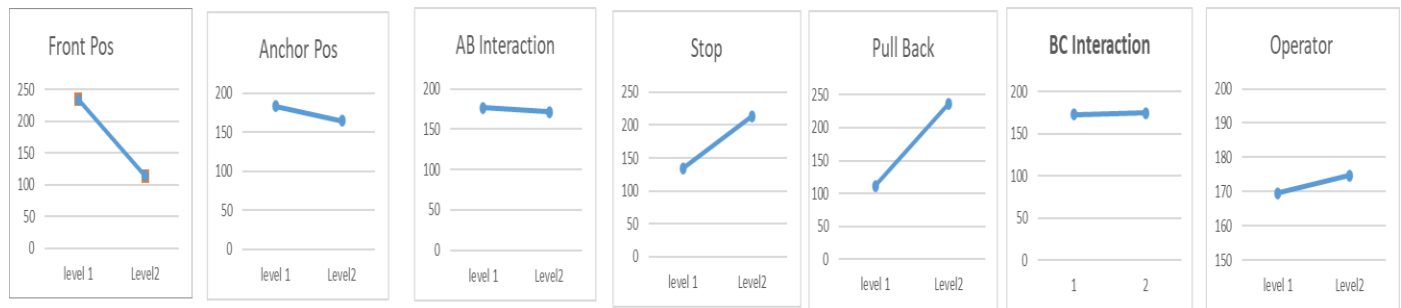


figure 2 – deviation key controls

3.1. Validation Exercise

Following completion of the main trials, a validation exercise was performed. This test focused only on the two primary key factors identified from the Taguchi analysis:

- Band Front Position (Levels 1 and 3)
- Pull-back Amount (Levels 140 and 170)

All other factors were held constant.

	KF1	KF2		1	2	3	Ave		
Firing 1	1	140	range	133	132	124	129.6667	KF 1 :1	KF2 :1
Firng 2	3	140	range	90	93	95	92.66667	213.8333333	111.1667
Firing 3	1	170	range	300	300	294	298	KF 1 :2	KF2 :2
Firng 4	3	170	range	225	220	225	223.3333	158	260.6667
								mid each factor	
								185.9166667	185.9167
								mid combined	
								185.9166667	

Table 2 – Validation results

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An additional firing test was conducted at mid-settings (Band Front Position = 2, Pull-back = 155), which produced an average range of 180.0 cm.

Summary of Validation:

- Calculated expected mid-range: 185.9 cm
- Measured mid-range: 180.0 cm
- Deviation: 5.9 cm (roughly 5.9 mm difference when considered proportionally against full distances)

This small deviation demonstrates strong predictive accuracy from the Taguchi analysis.

4. Interpretation of data

4.1. Key findings

Pull-back Amount was identified as the primary driver of distance (variably).

Trials using the higher pull-back value (170 units) consistently achieved significantly greater ranges compared to trials using the lower pull-back (140 units).

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This result aligns with basic physical principles, as greater elastic extension increases the stored potential energy, resulting in greater kinetic energy transfer to the projectile [2].

Band Front Position also had a notable effect.

A lower band front position (Level 1) typically produced longer ranges than a higher position (Level 3).

This is likely due to the increased effective stretch length and a more favourable launch angle when the band is anchored lower on the frame [3].

Band Anchor Position showed some influence on range, particularly when interacting with pull-back amount.

Trials with a farther anchor point generally resulted in higher launch energy, but the magnitude of this effect was smaller compared to the pull-back and front position factors.

Stop Position had a high measurable impact.

Adjustments to the stop position altered the final launch angle, which could fine-tune trajectory height and travel distance. However, the range changes caused by Stop Position alone were relatively modest.

4.2. Interaction effects

The experiment design also considered two key interactions:

- Band Front Position and Band Anchor Position (AB Interaction)
- Stop Position and Pull-back Amount (BC Interaction)

The data suggested that:

- The effect of Band Anchor Position was more pronounced when used in combination with larger pull-back settings.
- Variations in Stop Position became slightly more influential at lower pull-back levels, where launch energy was reduced and trajectory sensitivity increased.

However, in general, the main effects of Pull-back and Band Front Position dominated performance, and interaction effects were secondary.

5. Reflection

5.1. Human Variation

Despite efforts to standardize operator technique, some human variation was evident between Operator A and Operator B. Differences in hand strength, pull-back consistency and release technique influenced projectile distances even when identical settings were used. Although these variations were relatively minor, they highlighted the difficulty of achieving perfect consistency in manual operations [4].

In future experiments, mechanical pull-back measurement devices or trigger mechanisms could be introduced to further reduce operator-induced variability.

5.2. Noise factors

Several noise factors were identified during the experiment:

- **Axial Movement of the Catapult:**

During firings, slight left-to-right movement of the catapult occurred despite clamping it to the table.

This movement could influence launch direction and projectile range.

- **Setup Consistency:**

Small shifts in positioning between shots and minor adjustments to the apparatus between runs introduced unavoidable setup variability.

- **Operator Loading and Release Technique:**

Variations in how the projectile was placed and released also contributed to shot-to-shot inconsistencies.

The presence of noise factors highlighted how external and uncontrolled variables can affect experimental outcomes, even in relatively simple systems.

5.3. Lessons Learned

The experiment reinforced several key lessons:

- Even simple experimental setups can suffer from unexpected sources of variability.
- Human operators introduce an inherent degree of inconsistency that must be accounted for or minimised.
- Visual controls, consistent setup practices, and mechanical aids are important tools for improving experimental reliability.
- The Taguchi method proved to be an effective framework for identifying the dominant factors in system performance with a manageable number of trials.

Overall, the experience highlighted the importance of proactive noise control, careful experimental planning, and critical evaluation of results to ensure valid conclusions.

6. Conclusion

The key argument demonstrated through this experiment was that Pull-back Amount and Band Front Position were the dominant factors controlling the projectile range of the catapult. The Pull-back Amount had the greatest individual influence, with a larger pull-back (170 units) consistently producing longer ranges. The Band Front Position also had a significant effect, with a lower

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position (Level 1) generally leading to greater distances due to increased stretch and energy storage. Through application of the Taguchi method, these primary control factors were successfully identified without the need for exhaustive testing of every possible combination. Interaction effects, such as those between Band Anchor Position and Pull-back Amount, were noted but were secondary compared to the main factors.

By systematically applying structured experimental design principles and by managing noise factors such as axial movement and operator variability, the experiment successfully showed how mechanical system performance can be optimized through careful control of key settings. This reinforced the broader theme established at the outset: that controlled, structured experimentation is essential to identifying critical factors, improving reliability, and achieving repeatable results in real-world engineering applications.

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